

High-Performance SiC/SiC Ceramic Composite Systems Developed for 1315 °C (2400 °F) Engine Components

As structural materials for hot-section components in advanced aerospace and land-based gas turbine engines, silicon carbide (SiC) ceramic matrix composites reinforced by high-performance SiC fibers offer a variety of performance advantages over current bill-of-materials, such as nickel-based superalloys. These advantages are based on the SiC/SiC composites displaying higher temperature capability for a given structural load, lower density (~30- to 50-percent metal density), and lower thermal expansion. These properties should, in turn, result in many important engine benefits, such as reduced component cooling air requirements, simpler component design, reduced support structure weight, improved fuel efficiency, reduced emissions, higher blade frequencies, reduced blade clearances, and higher thrust.

Under the NASA Ultra-Efficient Engine Technology (UEET) Project, much progress has been made at the NASA Glenn Research Center in identifying and optimizing two high-performance SiC/SiC composite systems. The table compares typical properties of oxide/oxide panels (ref. 1) and SiC/SiC panels formed by the random stacking of balanced 0°/90° fabric pieces reinforced by the indicated fiber types. The Glenn SiC/SiC systems A and B (shaded area of the table) were reinforced by the Sylramic-iBN SiC fiber, which was produced at Glenn by thermal treatment of the commercial Sylramic SiC fiber (Dow Corning, Midland, MI; ref. 2). The treatment process (1) removes boron from the Sylramic fiber, thereby improving fiber creep, rupture, and oxidation resistance and (2) allows the boron to react with nitrogen to form a thin in situ grown BN coating on the fiber surface, thereby providing an oxidation-resistant buffer layer between contacting fibers in the fabric and the final composite. The fabric stacks for all SiC/SiC panels were provided to GE Power Systems Composites for chemical vapor infiltration of Glenn-designed BN fiber coatings (ref. 3) and conventional SiC matrices. Composite panels with system B were heat treated at Glenn (ref. 4), and the pores that remained open were filled by silicon melt infiltration (MI). Panels with system A and the other SiC/SiC systems were not heat treated, and remaining open pores in these systems were filled with SiC slurry and silicon MI.

TYPICAL PROPERTIES FOR 0°/90° CERAMIC COMPOSITE PANELS FABRICATED FROM VARIOUS CONSTITUENTS WITH ~35- TO 40-PERCENT TOTAL FIBER FRACTION

Composite type	Oxide/Oxide (ref. 1)	SiC/SiC	SiC/SiC	SiC/SiC (system A)	SiC/SiC (system B)
Fiber type	Nextel 720 ^a	Hi-Nicalon S	Sylramic	Sylramic-iBN (ref. 2)	Sylramic-iBN (ref. 2)
Fiber coating (or interphase)	None	BN	BN	BN (ref. 3)	BN (ref. 3)

Matrix type	Oxide (PIP) ^b	SiC-Si (CVI ^c + slurry + Si)	SiC-Si (CVI + slurry + Si)	SiC-Si (CVI + slurry + Si)	SiC-Si (CVI + ref. 4 + Si)
Ultimate tensile strength (UTS) at 20 °C, MPa	200	360	400	450	310
UTS at 20 °C after 100-hr burner exposure at 800 °C, MPa	200	170	240	450	300
Rupture strength after 100 hr at 800 °C in air, MPa	170	200	200	240	---
UTS at 1315 °C, MPa	<150	280	320	380	260
Rupture life at 105 MPa and 1315 °C in air, hr	<10	~500	~100	~500	>1000
Creep strain after 100 hr at 1315 °C and 105 MPa in air, percent	>0.2	0.05	0.2	0.05	0.02
Transverse thermal conductivity at 20 °C, W/m·°C	1.2	16	24	25	36

^aTotal fiber fraction, ~48 percent.

^bPIP, polymer infiltration and pyrolysis.

^cCVI, chemical vapor infiltration.

The table clearly shows that the panels with the SiC/SiC system A have the best combination of properties needed for hot-section engine components: (1) especially ultimate tensile strength, a property needed for component damage tolerance; (2) rupture strength and retained strength after burner rig exposure near 800 °C, a temperature region where environmental attack of SiC/SiC composites is typically the greatest; (3) ultimate

strength and rupture life at 1315 °C (2400 °F), a temperature well above the thermal capability of metal alloys (~1100 °C); (4) creep resistance, a key property needed for high-temperature dimensional control and intrinsic strength retention; and (5) thermal conductivity at 20 °C and higher, a property needed for reducing thermal gradients and stresses within the component. On the other hand, the panels with the Sylramic-iBN SiC/SiC system B, although they lose some ultimate strength during the composite treatment process, display state-of-the-art properties in terms of rupture life, creep resistance, and thermal conductivity. The microstructural sources for all these properties have been determined and modeled by Glenn researchers, and approaches for further improvements have been identified.

References

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